

## Low-profile dual-reflector antenna with double axial focus for beam-steering satellite communication terminals

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In the article, development of a reflector antenna for beam-steering satellite terminals is considered. Proposed was a design of a dual-mirror circularly polarised antenna with double axial focus, that has small longitudinal dimensions and a non-axisymmetric reflector shape. It was shown that such an antenna demonstrates a satisfactory level of aperture efficiency with a reflector aspect ratio of 1:0.35 and a longitude/diameter ratio of 0.35, which makes it suitable for mechanical beam steering in a limited space under the dome of the antenna system.

**Keywords:** dual-reflector antenna, beam-steering antenna, satellite communication, SatCom.

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The research into mobile means of receiving and transmitting satellite signals (SatCom systems [1,2] included) is progressing rapidly at present. The antenna of such systems must perform beam steering in the upper hemisphere. Mechanical or mechano-electrical steering is often used for these purposes [3,4]. Antenna arrays or reflector antennas are used as antennas for such systems [5,6].

Although antenna arrays provide high levels of gain, the relative simplicity and low weight of reflector antennas make them a viable option. It is also easier to excite circular polarization in a reflector antenna than in an array.

To implement beam steering in SatCom-type receiving and transmitting devices, the antenna should have as narrow a shape as possible so as to reduce the vertical dimensions of the entire system. Applied to reflector antennas, this implies that the reflector should have a near-rectangular shape with the height being much smaller than the width. Thus, a feed with an axisymmetric directional pattern (DP) (typical of circularly polarized antennas) cannot be used due to the flow of power over the reflector. Another restriction is the need to use deep short-focus reflectors in order to reduce the longitudinal dimensions of the system for ease of mechanical scanning.

Another advantage of reflector antennas is their wide operating frequency band. The frequency band of solutions based on printed antenna arrays is a few percent [7], whereas a reflector system may provide a frequency ratio of about 1.5, which is sufficient for operation in the entire Ku band.

Hat feed solutions are available for reflector antennas, but such designs are usually axisymmetric [8,9].

In the present study, we investigate the possibility of constructing a dual-reflector non-axisymmetric antenna with its main reflector having an aspect ratio of 1:0.35 and a longitude/diameter ratio of 0.35. This system is proposed to

be implemented with main and sub reflectors with double axial focus.

One way to obtain different DP widths in different planes while maintaining circular polarization is to use a sub reflector. The feed is an antenna with an axisymmetric DP. For the DP width to vary from one plane to the other, the profiles of the sub reflector in these planes should differ. Accordingly, the positions of its focus in orthogonal planes will be different, and in all sections the focal point lies on the longitudinal axis of the system (axis  $z$ ).

A hyperboloid is an effective design for the sub reflector, since it provides smaller longitudinal dimensions of the antenna system. The formula of a hyperbola for  $z(x)$  is known in explicit form:

$$z_{hyp}(x) = a \sqrt{\left(\frac{x}{b}\right)^2 + 1}, \quad (1)$$

where  $a$  and  $b$  are the semi-axes of this hyperbola. Let us rewrite the hyperbola equation in terms of focal parameter  $f$ , which is the distance from the focus of one branch of a hyperbola to the vertex of the other branch:

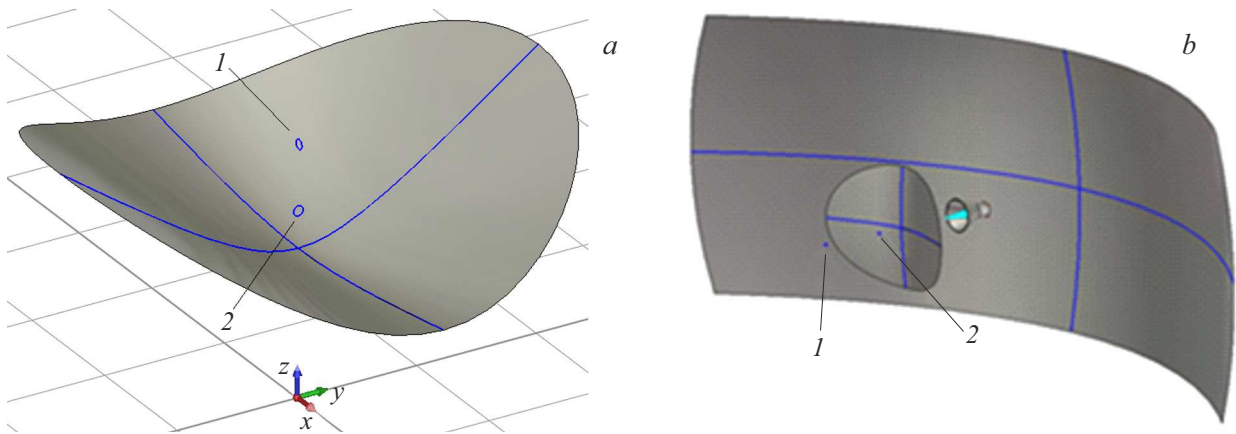
$$f = c + a = \sqrt{a^2 + b^2} + a,$$

where  $c = \sqrt{a^2 + b^2}$  is half the distance between the foci of a hyperbola. Thus,

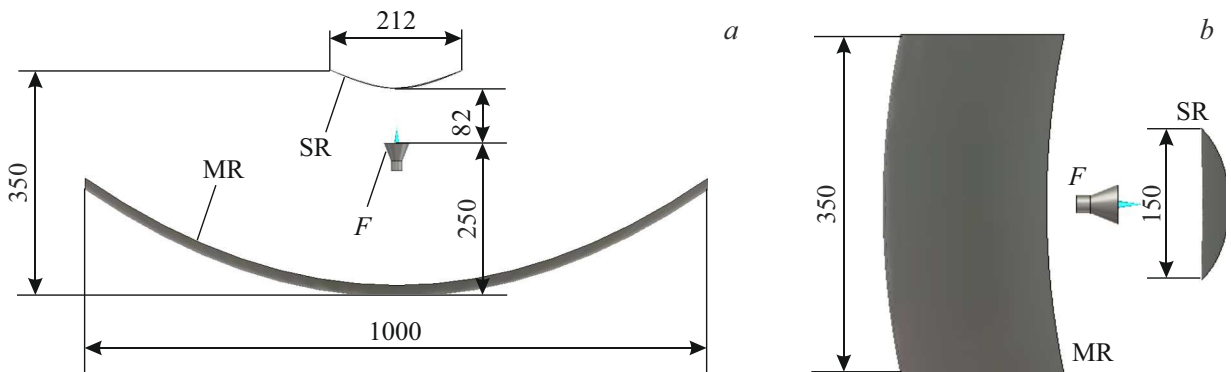
$$a = \frac{f^2 - b^2}{2f}. \quad (2)$$

Inserting (2) into (1), we obtain an explicit expression for the generator of a hyperbola in terms of focal parameter  $f$  and minor semi-axis  $b$ :

$$z_{hyp}(\rho, b) = \frac{f^2 - b^2}{2f} \sqrt{\left(\frac{\rho}{b}\right)^2 + 1}. \quad (3)$$



**Figure 1.** *a* — Diagram of a hyperboloid with double axial focus. *1* — Focus in plane  $xz$ ; *2* — focus in plane  $xy$ . *b* — Dual-reflector antenna with double axial focus. *1* — Focus in the vertical plane; *2* — focus in the horizontal plane.



**Figure 2.** Top view (*a*) and left view (*b*) of the antenna system with dimensions indicated (in mm). MR — main reflector, SR — sub reflector, and *F* — feed.

When a three-dimensional surface is constructed in cylindrical coordinates, the hyperbola profiles given by expression (3) are averaged with weights  $\cos \varphi$  and  $\sin \varphi$ :

$$z_{refl}(\rho, \varphi) = \sqrt{(z_{hyp}(\rho, b_1) \cos \varphi)^2 + (z_{hyp}(\rho, b_2) \sin \varphi)^2}, \quad (4)$$

where  $b_1$  and  $b_2$  are the minor semi-axes of hyperbolas forming a hyperboloid in orthogonal planes.

An example hyperboloid obtained using formula (4) is shown in Fig. 1, *a*. The focus (where the feed is positioned) is at the origin in this diagram.

The main parabolic reflector also has two foci, which are aligned with the foci of the hyperboloid. Its profile is calculated by formula (4) where  $z_{hyp}(\rho, b_1)$  is substituted with the equations of a parabola with different focal lengths.

The general view of the dual-reflector antenna system is presented in Fig. 1, *b*.

A conical horn with a conical dielectric insert is used as the feed of the dual-reflector antenna. This feed has a more stable position of the phase center than a dielectric cone, while remaining small in transverse dimensions. The feed was optimized according to the criterion of phase center stability and constancy of the DP width in the band.

The reflector geometry was obtained through numerical optimization of the model according to the criterion of maximum aperture efficiency in the frequency band (the feed geometry remained unchanged).

The dimensions of the entire antenna system are  $1000 \times 350 \times 350$  mm. The system thus fits into a cylinder 350 mm in diameter, which allows the antenna protected by a radio-transparent dome to be rotated mechanically about a horizontal axis.

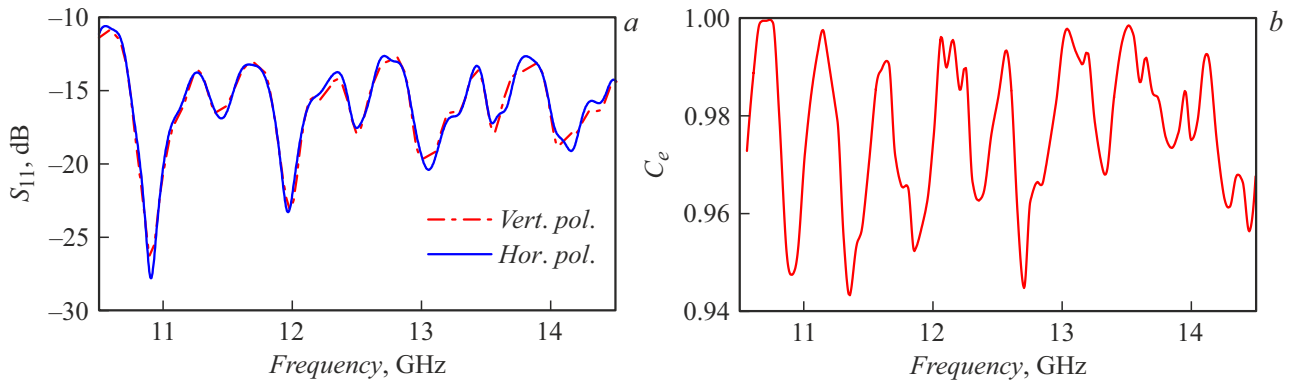
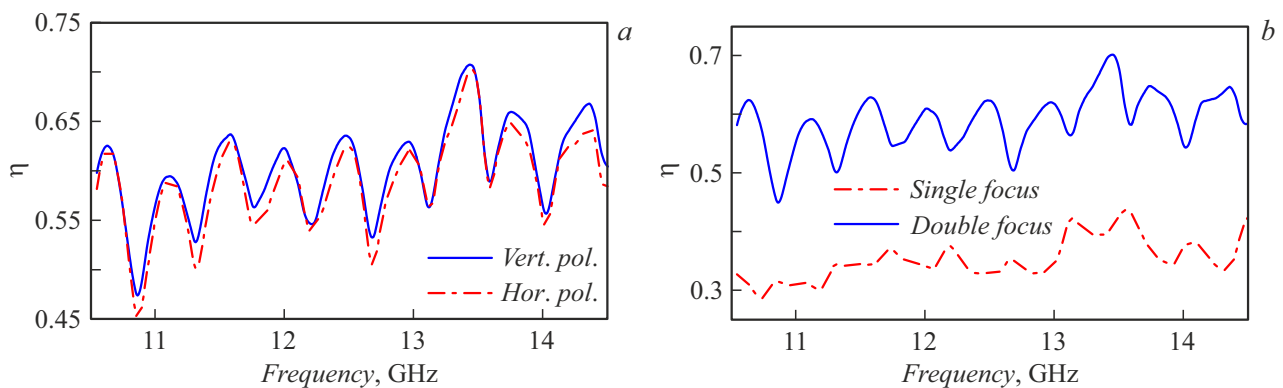
The diagram of the calculated antenna system with the main dimensions indicated is shown in Fig. 2.

The main geometric parameters of the antenna system are listed in the table. The frequency dependences of  $S_{11}$  (Fig. 3, *a*), ellipticity (Fig. 3, *b*), and aperture efficiency (Fig. 4, *a*) of the antenna system were obtained for two orthogonal excitation polarizations via numerical calculations. The ellipticity was determined for the system in which the feed was excited by two orthogonal polarizations with a phase shift of  $90^\circ$ .

Figure 4, *b* also presents a comparison of aperture efficiencies of the antenna with double focus and a similar antenna with single focus (i.e., a classical Cassegrain antenna). The latter system had the same dimensions and focal length,

Key geometric parameters of the antenna

Parameter	Horizontal plane	Vertical plane
Main reflector size, mm	1000	350
Sub reflector size, mm	212	150
Minor semi-axis $b$ of the hyperboloid, mm	85	54
Focal distance of the main reflector, mm	367	420
Focal distance of the sub reflector, mm	170	118
Longitudinal dimensions of the system, mm	350	


**Figure 3.** *a* — Reflection coefficient  $S_{11}$ ; *b* — ellipticity  $C_e$  of the antenna.

**Figure 4.** *a* — Aperture efficiency  $\eta$  of the antenna system for two orthogonal excitation polarizations; *b* — aperture efficiency  $\eta$  of the antenna with double focus compared to that of the antenna with single focus.

and parameters  $b_1$  and  $b_2$  of the sub reflector were set to 0.7 (this value was chosen through numerical optimization according to the criterion of maximum efficiency).

The calculation results reveal that the antenna system has a satisfactory efficiency combined with all the advantages of a dual-reflector system (rear feed, the possibility of construction without additional support rods) and small longitudinal dimensions. The band average efficiency is 0.58. The calculated ellipticity with excitation by a circularly polarized wave is close to unity within the entire frequency band.

The characteristics of the proposed antenna make it suitable for application in beam steering systems of SatCom satellite terminals, where the antenna may be rotated

in horizontal and vertical planes while fitting within the dimensions of a radio-transparent dome.

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## Conflict of interest

The authors declare that they have no conflict of interest.

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